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## **Location factors for logistics facilities: Location choice modeling considering activity categories**

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### **ABSTRACT**

While many past studies analyze the changes in the spatial distribution of logistics facilities and provide insights on the factors that drive the migration of logistics facilities, only a few studies analyze the factors of location choice at the individual facility level. Furthermore, the differences among various facility types, with respect to the key locational characteristics that attract logistics facility developments, are still not clear. This research attempts to fill the research gap by analyzing the location choices for logistics facility development. Using the data from the Paris Region, we characterize the locations and activities of logistics facilities and estimate a logistics facility location choice model for each activity category. The analysis reveals the key locational characteristics that influence logistics facility locations, such as zoning regulations, wholesale job accessibility, population density, and the accessibility to autoroute (controlled-access highway), as well as the heterogeneity in the effects of these characteristics by activity category. Zoning and traditional clusters play a significant role for the locations of newly developed logistics facilities, which underlines the importance of public policies for logistics land use in the Paris region. The effect of the accessibility to population is identified for the group of facilities which serve for retail shops and end-consumers only under the assumption that alternative locations are limited to specialized economic activity/logistics zones, indicating that population accessibility is a secondary factor to the designation as the specialized zone. Zoning changes to/from economic activity/logistics zones may cause significant impacts on the spatial distribution of logistics facilities, and thus, the distribution of goods vehicle traffic flow.

Keywords:

Freight; logistics facility; land use; location choice modeling; city logistics; Paris Region

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## 1. Introduction

In the past several decades, the transformation of urban logistics facility systems has been observed. The evolutions in supply chain management and logistics practices have led to the changes in the functions and locations of logistics facilities (Hesse and Rodrigue, 2004). As a result, the outward migration of logistics facilities, so called “logistics sprawl”, has occurred and been verified in many cities around the world (Aljohani and Thompson, 2016). While a large number of studies analyze the changes in the spatial distribution of logistics facilities and provide insights on the factors that drive the migration of logistics facilities, only several studies analyze the factors influencing location choice at the individual facility level (Woudsma et al., 2008; Sakai et al., 2016; Kang, 2018; Gingerich and Maoh, 2019). Furthermore, to the best of our knowledge, none of those studies focus on the differences among different activity types, with respect to the key locational characteristics that attract logistics facility developments. Heitz et al. (2018) point out that such knowledge is lacking in the literature despite its importance. For example, the features of a location that attract storage activities should be different from those that are important for cross-docking facilities. The lack of quality data hampers an in-depth analysis of the heterogeneity within the large category of “logistics facilities” and creates the research gap.

In this paper, we aim to fill the research gap by analyzing the location choices for logistics facility development using the data for the Paris Region. The Paris Region is the most populous region in France and plays a role as a key logistics hub in Europe (Guerrero and Proulhac, 2014). Heitz et al. (2017) developed a high-quality dataset of logistics facilities in the Paris Region that covers various characteristics of the facilities and proposed a new typology of logistics facilities based on the operator’s industrial sector and the facility’s primary function. We use the dataset of the spatial distribution of logistics facilities in the Paris Region prepared by Heitz et al. (2017) for understanding the location factors through the estimation of location choice models for different categories. The identification of key location factors for logistics facility development and the comparison of the location choice models for the facilities of different types are expected to provide valuable insights for designing urban logistics land-use policies.

The rest of the paper consists as follows; Section 2 provides the literature review, focusing on the recent studies about the spatial distribution of logistics facilities and those using quantitative approaches to clarify the key factors influencing logistics facility location choice; Section 3 gives the overview of the spatial characteristics of logistics facilities in the Paris Region; Section 4 describes the typology of logistics facilities adapted to the data in the Paris Region; Section 5 discusses the data used and the analytical approach, specifically the modeling approach for logistics facility location choices; Section 6 discuss the results of the analysis; and Section 7 concludes the research with land use policy implications from the analysis.

## 2. Literature review

Although the locations of logistics facilities have been studied at the regional and national scales (e.g. Bowen, 2008; Rivera et al., 2014; Holl and Mariotti, 2018) as well as at the urban/metropolitan scale, in this section, we discuss the past studies of the spatial distribution and location factors of logistics facilities at the metropolitan scale, which is the focus of our research.

### 2.1 Studies on the spatial distribution of logistics facilities

The evolution of logistics operations, together with the innovations in the information and communication technologies (ICT) in the 1990s, has been progressing the demand-driven supply chain management. The demand for logistics facilities has largely shifted from traditional warehouses, which are primarily for storage, to distribution centers with large footprints for facilitating seamless goods flow (Hesse and Rodrigue, 2004). The roles of such distribution centers vary by the distribution system (e.g. hub-and-spoke) and the position in the system (e.g. regional hubs and local distribution facilities). Such change has affected logistics facility locations. In the last ten to fifteen years, many researchers have studied the spatial pattern of logistics facility locations for identifying trends in the spatial process. Some metropolitan-scale studies focus on “logistics sprawl”, which is the increase of logistics facilities in peripheries of cities (Dablanc and Rakotonarivo, 2010; Dablanc, 2014). Case studies show that many metropolitan regions experienced this spatial process (Aljohani and Thompson, 2016; Dablanc et al., 2017; He et al., 2018). These studies identify the development of logistics facilities in suburban areas and/or the conquest of urban fringes by logistics real estate developers and third-party logistics operators (Raimbault, 2015). Logistics sprawl draws attention due to its potential impacts on urban traffic and environment. Some researchers study into the negative impacts of logistics facilities in peripheral areas (Andriankaja, 2014; Sakai et al., 2015, 2017, 2019). Heitz (2017) analyzes the different strategies for locating or relocating logistics activities in dense urban and suburban areas, putting emphasis on the availability and land price.

## 2.2 Quantitative approach to identify the factors for logistics facility location choice

The quantitative analysis of business locations for identifying influencing factors has been conducted in various disciplines for a long period (Moeckel, 2013), although those focusing on logistics facilities are relatively new. One of the early works that use a discrete choice modeling approach for such purpose is Hagino and Endo (2007). They estimate a multinomial logit (MNL) model for the locations of regional freight facilities and distribution centers, using 2003 Tokyo Metropolitan Freight Survey (TMFS) data. Using the model, they estimate the zonal potentials for logistics land-use development and quantify the influences of highway developments and zoning regulations. Woudsma et al. (2008) estimate spatial lag models for Calgary, Canada, to evaluate the effects of accessibility indicators to logistics land use. Their analysis underlines that accessibility based on the level of congestion, which is isolated from the effect of travel distance, has a strong influence on the logistics land use development. Van den Heuvel et al. (2013) analyze the locations of logistics establishments and their concentrations in North Brabant, Netherlands, 1996 and 2009. One of the key findings is that the experience of the operation in a cluster of logistics activities leads to higher potential for a business to choose a place where logistics activities concentrate even after its relocation. Durmus and Turk (2014) estimate a binary logit model for evaluating the factors that drive the concentration of warehouses in Istanbul, Turkey. Their model shows the significant effects of transport accessibilities, industrial and commercial clusters, rents, the distances to the city center and customs. Verhetsel et al. (2015) use the data from a stated preference survey to estimate MNL and mixed multinomial logit (MMNL) models for the location choices of logistics firms in Flanders, Belgium. The estimated models indicate that the land rent is the most important factor. The distribution of warehouses is analyzed from the perspective of environmental justice by Yuan (2018). His regression models highlight the association between minority neighborhoods and warehouse locations in the Los Angeles metro area, U.S.

A few recent researches apply the discrete choice modeling for the location choices of logistics facilities, as with Hagino and Endo, using observed logistics facility locations. Sakai et al. (2016) estimate MNL models for the locations of logistics facility development during 2003-2013 in Tokyo metropolitan area, Japan. The alternatives are 1 km by 1 km polygons and the indicators of accessibilities, land characteristics, and zoning are considered as independent variables. They consider the area of developable land as a scale parameter. Taking advantage of the shipment records available for facilities, their models consider an accessibility to shippers/receivers, specific to each logistics facility, which shows very strong effect on location choice. Also, their analysis highlights the difference in the location choice mechanism by logistics facility size. Furthermore, they integrate the location choice models, with modifications, into an urban logistics land-use and traffic simulator called ULLTRA-SIM (Sakai et al., 2019) to evaluate the externalities attributable to the spatial distribution of logistics facilities. Kang (2018) estimates MNL models, using a cross-section data, i.e. warehouses that exist in 2016, in Los Angeles, U.S. Kang segments the samples by the year of construction (1951-1980, 1981-2000, and 2001-2016) for evaluating the effects of demographic characteristics and accessibility factors on the location choice mechanism. Kang uses census tracts as alternatives without considering their sizes, which potentially leads to biases in coefficient estimation. Kang's analysis identifies the growing effects of the accessibilities to inter-regional markets in the LA. Gingerich and Maoh (2019) also estimate MNL models using the data of 489 warehouses that exist in Toronto, Canada, 2015. Their model identifies the significant effects of the share of industrial use, airport and highway accessibilities, rural/non-rural, and land price. Same as Kang, the census tracts of unequal sizes are alternatives and neither of the size and land availability of alternatives is not taken into account, which makes the coefficient estimates unreliable. Furthermore, they use a cross-section data of existing firms, mixing the warehouses developed in different years.

## 3. Logistics facilities in the Paris Region

### 3.1 Locations of logistics facilities

The Paris Region has experienced logistics sprawl in the past few decades (Dablanc and Rakotonarivo, 2010; Raimbault and Bahoken, 2014). At present, only 1% of logistics facilities are located within the City of Paris (Heitz et al., 2017) (Figure 1). Most of those facilities were developed as part of the city's projects. Several urban consolidation centers (such as Beaugrenelle, Les Halles, and Concorde) or "logistics hostels" (Chapelle Internationale), which combine logistics and tertiary functions, have been funded by public stakeholders (Raimbault et al. 2019). The abandoned areas and unused parking lots were redeveloped for the purpose of accommodating logistics facilities, most of which are rather small. Other 47% of logistics facilities are located in the inner suburbs (Heitz et al., 2017) with an average size of about 5000 m<sup>2</sup>. Many of these facilities are old, used for traditional logistics practices, and do not meet modern standards. However, the inner suburbs remain an important area for logistics facilities because of major transport infrastructures (river ports and airports) and

logistics and industrial zones. The remaining 52% of logistics facilities are located in suburban areas, the outer departments of the Paris Region, which have low-to-medium population density (Heitz et al., 2017). Many of them are relatively new and clustered in private logistics parks (Bounie, 2017; Raimbault, 2015). The suburban real estate market is characterized by large and standardized facilities. In the periphery and the outside of the main cluster of the urbanized area, logistics facilities are located mainly in small urbanized poles and those located in rural areas are limited.

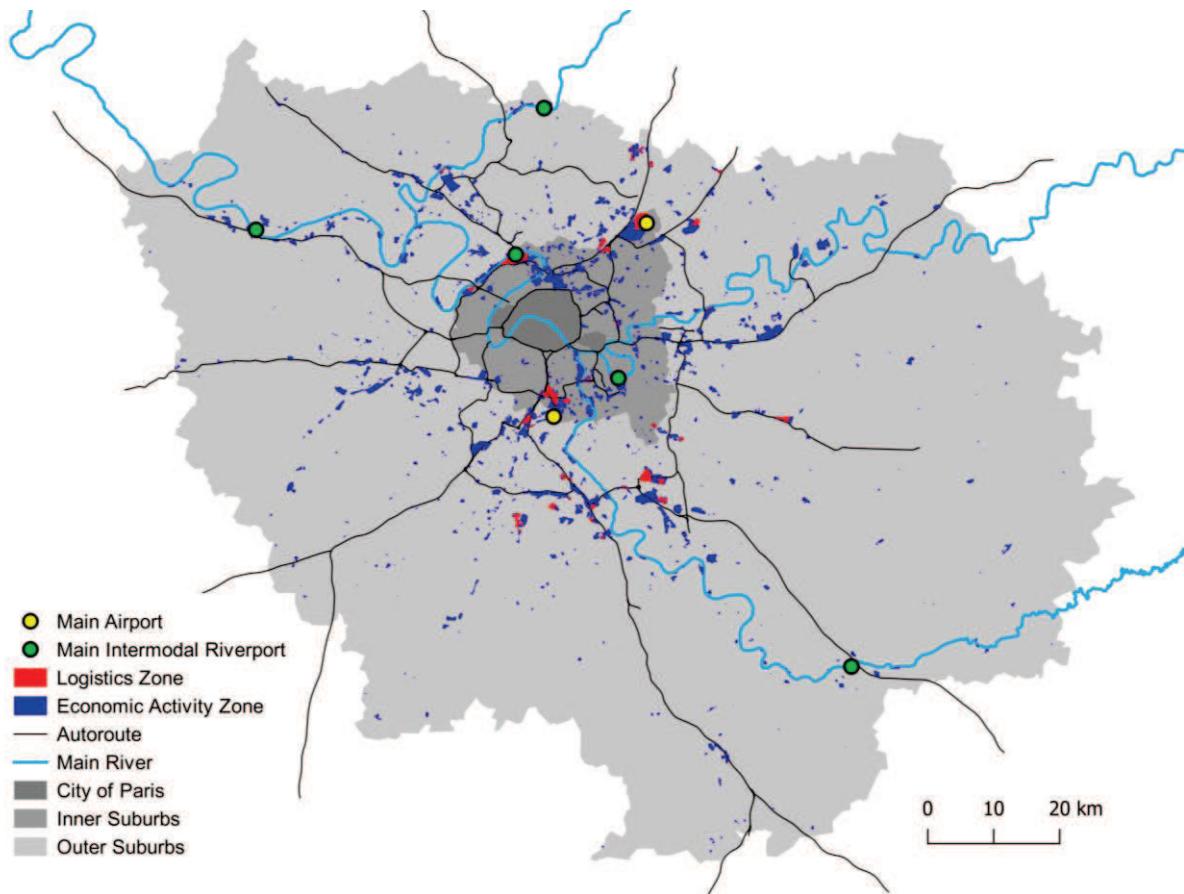


Figure 1. Transport infrastructure and logistics and economic activity zones in the Paris Region

### 3.2 Zoning for logistics facilities

In France, Economic Activity Zones (EAZs) refer to specific areas reserved for the installation of firms. They may involve commercial, industrial, services, artisanal, logistics or mixed activities. They are usually placed under the jurisdiction of local public authorities, who produce plans and regulations, grant building permits, and create and maintain these zones. EAZs strongly impact the locations of logistics facilities as they provide logistics firms with locations near road transport nodes and/or in proximity to the agglomeration's core yet outside of mixed-use or residential areas, where logistics activities are often a nuisance for inhabitants and other activities. On the other hand, Logistics Zones (LZs) specifically reserve land for logistics facilities and about 90% of them are located within EAZs. The designation of LZs in EAZs is not unique to France. Also, in other European countries, LZs can be located within EAZs (e.g. Belgium (Merenne-Schoumaker, 2007)). They can be either public, semi-public or developed by the operators of transport infrastructure such as river ports (e.g. Bonneuil and Gennevilliers) and airports (Roissy-Charles-de-Gaulle and Orly). These infrastructure operators foster the development of logistics facilities in their lands regardless of the use of their multimodal infrastructures. LZs allow logistics facilities to cluster, as they are less vulnerable to policy changes and market forces, and more likely to remain in high-density areas close to the urban core and with good road accessibility.

## 4. Typology of logistics facilities

Most studies attempting to identify and classify logistics facilities at the local or national level rely on activity codes used in business registries (Bowen, 2008; Cidell, 2010; Heitz and Dablanc, 2015). NAICS (North American Industry Classification System) and NACE (the Statistical Classification of Economic Activities in the European Community) are examples of such activity codes. However, the use of activity codes to characterize facility types in the logistics sector is often impractical, which holds true in France due to the following two reasons. First, the categories applied for the codes are too broad and imprecise to describe a series of activities common in the logistics sector. For example, some freight terminals are used as logistics hubs at locations where goods are transferred from long distance haulage to urban distribution, and vice-versa. The activity of such facilities does not fit to the French NAF classification<sup>1</sup>, which distinguishes 49.41A (interurban freight road transport) from 49.41B (proximity freight road transport); freight terminals, by definition, refer to both codes. Furthermore, while warehouses are typically for storage, some of them are also used for freight handling, sorting, consolidation and break-bulk, order processing, labelling and/or packaging activities. Second, in the French company and establishment database, activity codes are based on the declarations by firms upon creation and sometimes informed erroneously. Scrutinizing the data collected for the Paris Region, Heitz et al. (2017) found a number of establishments which share similar logistics activities but are different in activity code. Even the same company's establishments performing the same tasks are sometimes characterized by different codes.

A practical typology of logistics facilities must require a tailored approach. Several classification frameworks are proposed in the literature. Some require quantitative analysis and modeling (Beziat et al., 2015). The classification proposed by Tavasszy (2000) relies on value density and perishability of goods handled, packaging density, delivery time, size of shipments, and demand frequency, to build a group of categories called 'logistics families'. Others rely on extensive interviews with firms and transport operators (Bolis and Maggi, 1999; Burmeister, 2000), which allows for comprehensive and detailed information of companies' logistics organizations – linked to market-based relations with other firms, collection of resources, production processes, degrees of horizontal/vertical integration and spatial distribution of establishments – but is not applicable to a large sample set. The third, an intermediate option, is to rely on information available on the specialized press and companies' websites to identify the market segments of the companies operating the facilities as well as operational information (Carbone and Stone, 2005; Protrans, 2000; Strale, 2013). Taking this approach, Heitz et al. (2017, 2019) propose a classification method and apply it to the dataset for the Paris Region. Each logistics facility in the dataset is assigned a category based on its activity. The activities of logistics facilities are informed through field studies and visits to the companies' websites, which provide descriptive, though admittedly heterogeneous, data on their activities.

Heitz et al. (2017) took a systematic approach to overcome the heterogeneity of collected information. They identified the following four criteria impacting logistics organizations from the literature review:

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<sup>1</sup> NAF stands for *Nomenclature d'Activité Française*, which describes the French Economic Sectors in 732 classes. The nomenclature is very similar to the NACE classification system.

- *Function*: Cross-dock operation (i.e. a terminal), storage (i.e. a warehouse), or both.
- *Operator*: A third-party logistics provider or a shipper. The facilities of shippers are further broken down based on the core-activity of the company (i.e. wholesale, manufacturing, or retail).
- *Type of goods*: The nature and packaging (size and weight) of the goods handled.
- *Destination of goods*: Households, companies, or both; the terminals sending to companies are further broken down based on the type of companies to be served.

These criteria are used to categorize logistics families into one of twenty categories, for which the details are available in Heitz et al. (2017, 2019). Heitz et al.'s typology allows for a hierarchical classification of logistics facilities. In this paper, we use the top two levels of this hierarchical structure, i.e. function and operator, to analyze the differences on location choice decisions. A framework of the typologies, simplified from that proposed by Heitz et al., is shown in Figure 2.

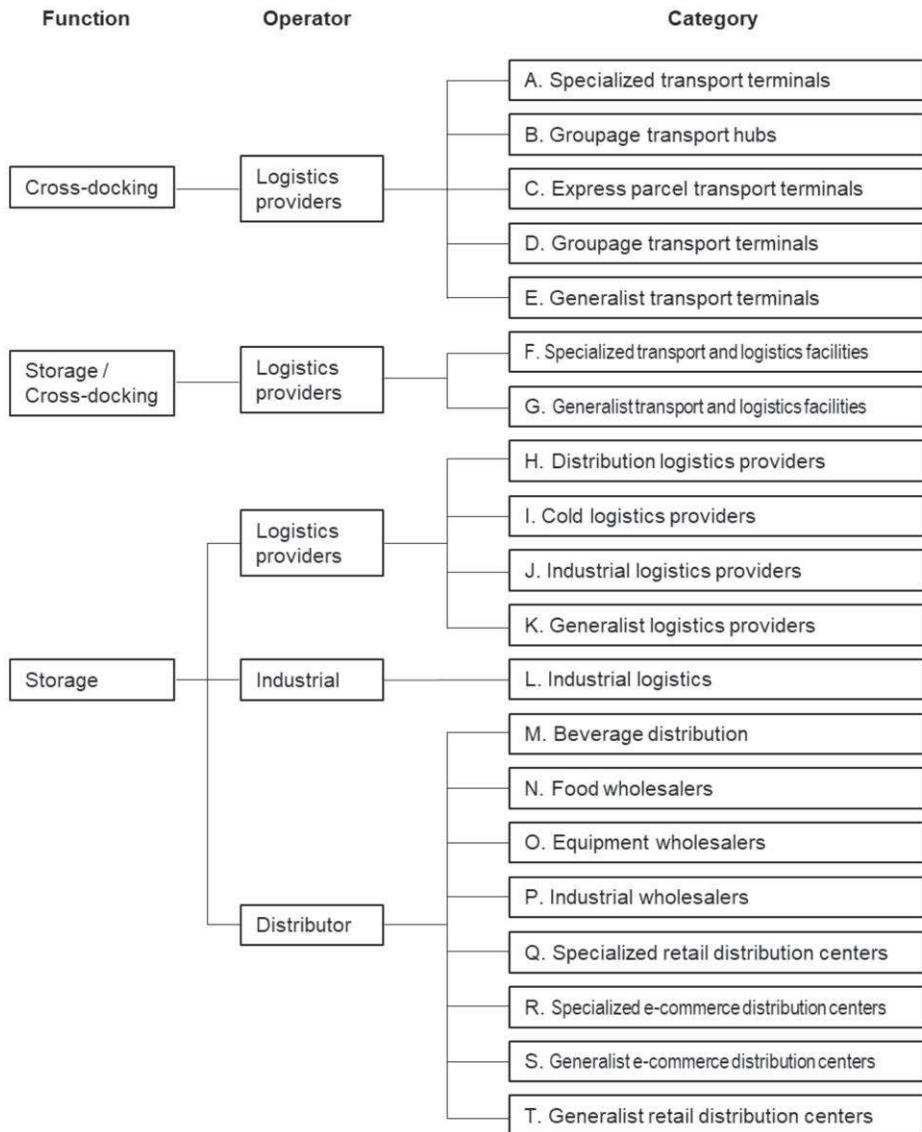


Figure 2. A framework of logistics facility typologies (simplified from Heitz et al. (2017, 2019))

## 5. Analysis of location choices for logistics facilities

### 5.1 Logistics facility data

We use a subset of the data of logistics facilities that exist in the Paris region (the Ile-de-France), 2013; we use the data of 826 logistics facilities established during the period of 2003-2013 (Table 1). We also tested the segmentation of the logistics facilities based on the establishment year (i.e. 2003-2007 and 2008-2013) to check the potential influence of the 2008 Financial Crisis. We found no significant difference between the two periods throughout the analyses presented in this paper. Following the typology proposed by Heitz et al. (2017), we segment the logistics facilities into five categories: (i) facilities operated by logistics service providers (LSPs) exclusively for cross-docking (LSP-CD), (ii) storage and cross-docking facilities operated by LSPs (LSP-CD/S), (iii) storage facilities operated by LSPs (LSP-S), (iv) storage facilities operated by manufacturers (MFR-S), and (v) storage facilities operated by distributors (either wholesalers and retailers) (DISTR-S). Storage facilities require larger sites than the facilities with cross-docking function: the average land size is the largest for LSP-S and the smallest for LSP-CD/S. The spatial distribution of sample facilities is shown in Figure 3.

Table 1: Number of samples and the average land size by facility group

	LSP-CD	LSP-CD/S	LSP-S	MFR-S	DISTR-S
No. of samples	186	110	202	75	251
- Samples within EAZs/LZs	146	87	144	59	151
Average land size (m <sup>2</sup> )	5,444	5,370	16,759	10,926	9,693

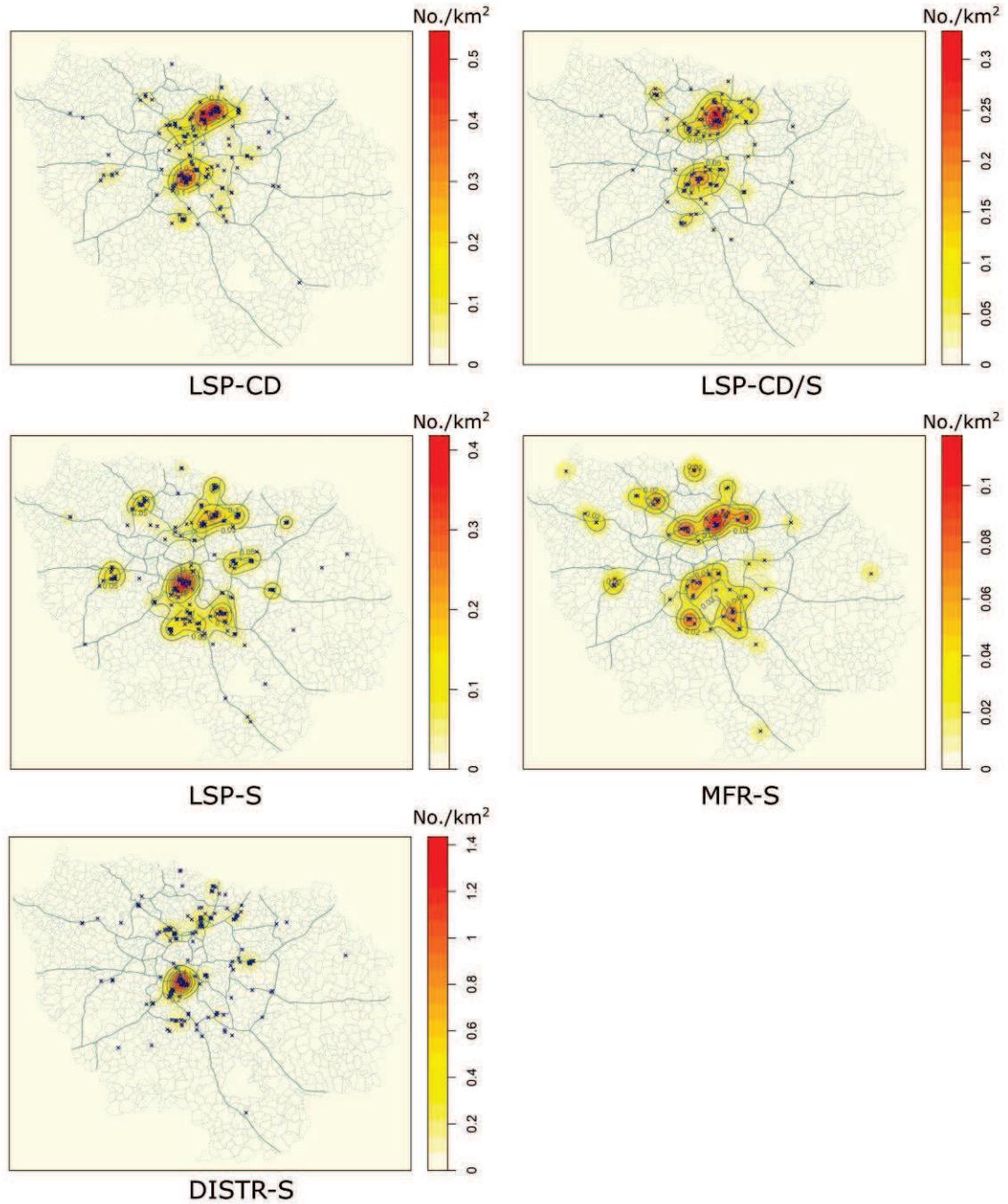
*LSP-CD* are operated by transport companies handling less-than-truckload shipments (usually less than 3 tons), most of which focus on specific segments of shipment demand in terms of size and packaging (parcels, pallets, or atypical shipments) (Beziat et al., 2015). These facilities are often integrated in hub-and-spoke networks. While most facilities have their own delivery and pick-up catchment areas, a small share of the facilities function as national, continental or global hubs. Usually, shipments are stored for no more than a few hours in those facilities.

*LSP-CD/S* are mostly operated by small local companies, which are often traditional carriers handling heterogeneous cargo and subcontractors serving for larger companies. Atypical shipments, i.e. those uncommon in terms of size, volume, weight, packaging, delivery time, and origin-destination pairing, still require carriers, but logistics networks of large companies are often not suitable for them. The operators of the facilities in *LSP-CD/S* fill such gaps. Their services are extensive, covering cross-dock operations, short-term and long-term storage, or even end-to-end transportation, depending on the needs of their clients.

*LSP-S* are operated mainly by non-traditional transport companies that provide specialized storage and related services (such as transportation, inventory management, fleet management, shipment consolidation and/or order processing) for both short and long terms. Offering such services allows clients to focus on their core businesses. They offer tailor-made services for fulfilling their clients' needs including multi-dimensional services: management of complex supply chain services, software and consulting to help clients develop efficient transport networks, billing, cost-tracking or rate negotiation services among others. The recent rise of these types of operators has led to the growth of a real-estate market dedicated to the needs of these businesses (Raimbault, 2015).

*MFR-S* are mostly traditional warehouses, which were common before the 1990's. These facilities are operated by manufacturing firms, mainly to store parts before assembly or to store produced goods. They are usually isolated buildings located close to manufacturing facilities.

As for *DISTR-S*, wholesaler's facilities serve two purposes: to collect finished or almost-finished products from producers and gather those products in bulk, and to break large cargos to small ones to deliver them to retailers. Most wholesalers handle only one commodity type. Retailers' facilities can be either for specific products (e.g. clothes, furniture or electronic products) or heterogeneous ones (for supermarkets and hypermarkets) depending on the business function. The largest retailers often own their facilities and operate some of them (if not all), while others rely on the facilities operated by LSPs.



Note: “x” markers indicate logistics facility locations.

Figure 3. The spatial distribution of sample logistics facilities

## 5.2 Analytical approach

We use the multinomial logit (MNL) model to model the location choices for logistics facility developments. The unit of choice set is 1 km-by-1 km polygon. This unit is selected to accurately consider some independent variables (IVs), such as accessibilities, while keeping the computational cost for the model estimation reasonable. In case a polygon is located across more than one municipality, the polygon is divided along the municipality boundary so that each alternative location belongs to only one municipality; such arrangement is needed as some variables are available only at the municipality level. In total, 23,666 alternative locations are considered (Figure 4).

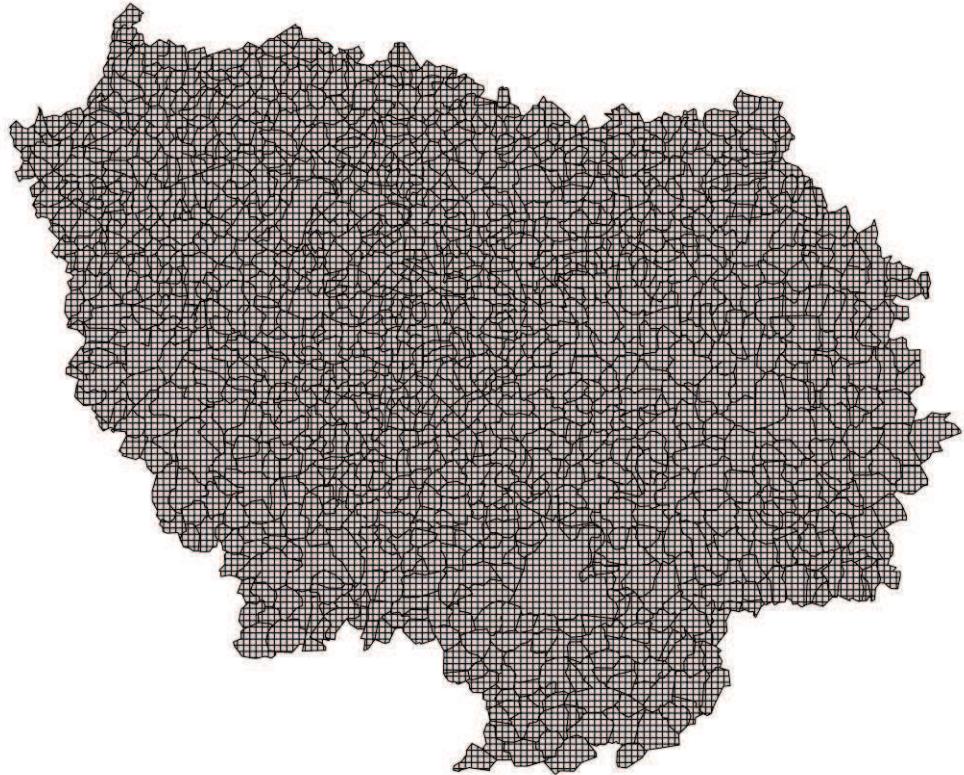


Figure 4. The choice set for estimating multinomial logit models

The utility of location  $l$  for a logistics facility consists of an observed deterministic component and a randomly distributed unobserved component as follows:

$$U_l = V_l + \varepsilon_l \quad (1)$$

where:

$V_l$ : an observed deterministic component

$\varepsilon_l$ : a randomly distributed unobserved component

Before deciding the final set of independent variables to be included in the deterministic component, we tested various combinations of variables, which include population and employment densities and accessibilities, accessibilities to various transport facilities (autoroute, airport, freight terminal, river container terminal, and intermodal terminals), and zoning (the shares of EAZ and LZ). The data of land price/rent, a key variable identified from the past research, was not available for the modeling. We consider population density as a proxy of land price (and of the degree of the conflict with passenger trips). (Kang (2018) also uses density variables as proxies of land price.) Also, while Sakai et al. (2016) show the accessibility to shippers/receivers specific to each logistics facility increases the model fit, we use the accessibility variables common to all logistics facilities due to the data limitation. It must be noted that, due to the complex correlation structure among considered variables, the specification process is not as straightforward as a simple significance test for each variable. Finally, only five variables were included because these variables achieve good model fits, provide the expected signs of coefficients without high correlations among variables, and clarify the important factors for location choices. The deterministic component of the utility of alternative location  $l$  for a logistics facility is determined by the following function:

$$V_l = \beta_{EAZ} \log(ShareEAZ_l) + \beta_{LZ} \log(ShareLZ_l) + \beta_{Whls.Emp.} \log(Whls.Emp._l) + \beta_{Pop.Dens.} \log(Pop.Dens._l) + \beta_{Dist.to Auto.} \log(Dist.to Auto._l) \quad (2)$$

where:

$ShareEAZ_l$  : The share of Economic Activity Zones in location  $l$

$ShareLZ_l$  : The share of Logistics Zones which is not the part of Economic Activity Zones in location  $l$

$Whls.Emp._l$  : Number of jobs for wholesale industry within 3 km of location  $l$

$Pop.Dens._l$  : Population density of a municipality which location  $l$  belongs to (per km<sup>2</sup>)

$Dist.to Auto._l$  : Distance from location  $l$  to the nearest autoroute (i.e. highway) ramp (km)

$\beta_{EAZ}, \beta_{LZ}, \beta_{Whls.Emp.}, \beta_{Pop.Dens.}, \beta_{Dist.to Auto.}$  : Parameters to be estimated

As mentioned earlier, roughly 90% of LZs are also the EAZs in the Paris Region. In our models, we consider the share of LZs which is not the part of EAZ as an IV, in addition to the share of EAZs. Such arrangement for the two zoning regulations leads to, again, higher model fits than the other arrangements. As the utility function in equation (2) includes a municipality level variable, we also estimated the nested logit (NL) models using 1300 municipalities as the upper level alternatives; however, the estimated ratios of the scale parameters for lower- and upper-level utilities indicate the independence among the lower-level alternatives within an upper-level one; therefore, we decided to present only MNL models.

The summary statistics of the independent variables are shown in Table 2. All the five IVs are log-transformed and normalized before the model estimation. The share of EAZ is calculated based on the 2013 data provided by the Ile de France Region Planning Agency (IAUIDF). The data of LZ is based on an ad-hoc census of logistics zones built by the French consulting firm, Samarcande; it was further improved and refined by Bounie (2017). Employment (wholesale) and population statistics for the year 2014 are obtained from the French National Institute of Statistics (INSEE). 2015 road network data from the Route 120® database are used for calculating the distance to the nearest autoroute ramp.

Table 2: Summary statistics of independent variables (before log-transformation and normalization)

	Mean	Median	SD	Min	Max
Share EAZ (%)	2.77	0.00	12.67	0.00	100.00
Share LZ (%)	0.05	0.00	1.33	0.00	90.41
Whls. Emp. (thou.)	1.70	0.11	6.06	0.00	95.94
Pop. Dens. (thou./km <sup>2</sup> )	1.14	0.12	3.27	0.00	41.86
Dist. to Auto. (km)	9.59	7.28	8.19	0.10	45.97

Assuming the random component in equation (1) follows Type 1 extreme value distribution, the probability for location  $l$  to be selected for a logistic facility is:

$$P_l = \frac{\exp(V_l + \ln S_l)}{\sum_{l' \in L} \exp(V_{l'} + \ln S_{l'})} \quad (3)$$

where:

$S_l$ : The available area at location  $l$

$S_l$  is obtained by subtracting the sizes of forest land use, semi-natural land use, agricultural land use, water land use, artificial spaces (parks, gardens, and open-air sports fields), individual housing, collective housing, social facilities (education, health, leisure, tourism, etc.), transport infrastructure, and landfills, quarries & construction sites from the size of location  $l$ , based on the data of Land Cover Mode (MOS) data from IAUIDF.

## 6. Result and discussion

The estimated model coefficients are shown in Table 3 and Table 4. First, the combined effect of  $ShareEAZ$  and  $ShareLZ$  is very strong for all the five groups. In the Paris Region, zoning regulation plays a significant role for logistics facility development in general. The effect is especially strong for  $LSP-S$ . They are largely in prime locations in publicly/privately planned or public-private freight villages or economic activity zones. Next,  $Whls.Emp.$ , the accessibility to the jobs in the wholesale industry, is also a significant factor at 95% confidence intervals for all groups except  $MFR-S$ . The locations which have the highest wholesale job accessibilities are the traditional clusters of wholesale businesses close to two airports: Charles de Gaulle Airport and Paris Orly Airport.

We consider  $Pop.Dens.$  as a proxy of land price and also the degree of the conflict with passenger trips. This IV shows the significant negative effects for  $LSP-S$  and  $DISTR-S$  while being insignificant for  $LSP-CD$ ,  $LSP-CD/S$  and  $MFR-S$ . The estimated effects for  $LSP-S$  and  $DISTR-S$  are understandable as they require large sites. On the other hand, facilities in  $MFR-S$ , which also require large sites, are insensitive to  $Pop.Dens.$ ; for them,  $ShareEAZ$  and  $ShareLZ$  are only factors that have significant effects. Finally,  $Dist.to Auto.$  is significant only for  $DISTR-S$ . Seemingly, a large serving area associated with a facility in this group makes locations with good highway accessibility advantageous for deliveries.

Table 3: Estimated location choice models (LSP-CD, LSP-CD/S, and LSP-S)

	LSP-CD			LSP-CD/S			LSP-S		
	Coef.	t-val.	p-val.	Coef.	t-val.	p-val.	Coef.	t-val.	p-val.
log(ShareEAZ)	0.91	15.4	$7.9 \times 10^{-35}^{**}$	1.21	12.8	$2.1 \times 10^{-23}^{**}$	1.34	18.4	$7.9 \times 10^{-45}^{**}$
log(ShareLZ)	0.11	12.0	$7.5 \times 10^{-25}^{**}$	0.04	2.02	$0.046^{**}$	0.08	7.42	$3.2 \times 10^{-12}^{**}$
log(Whls. Emp.)	1.49	5.80	$2.8 \times 10^{-8}^{***}$	0.75	2.25	$0.026^{**}$	0.91	4.03	$7.9 \times 10^{-5}^{**}$
log(Pop. Dens.)	-0.24	-1.55	0.123	0.07	0.34	0.735	-0.60	-4.54	$9.7 \times 10^{-6}^{**}$
log(Dist. to Auto.)	0.02	0.16	0.873	-0.02	-0.17	0.865	0.10	1.11	0.268
L (0)		-1873			-1118			-2035	
L ( $\hat{\beta}$ )		-1270			-754			-1377	
$p^2$		0.322			0.326			0.324	
$\bar{p}^2$		0.319			0.322			0.321	

Note: \*Significant at 90% confidence level; \*\*significant at 95% confidence level

Table 4: Estimated location choice models (MFR-S and DISTR-S)

	MFR-S			DISTR-S		
	Coef.	t-val.	p-val.	Coef.	t-val.	p-val.
log(ShareEAZ)	1.28	11.4	$5.2 \times 10^{-18}^{**}$	1.15	17.1	$7.8 \times 10^{-44}^{***}$
log(ShareLZ)	0.07	3.87	$2.3 \times 10^{-4}^{**}$	0.10	13.0	$6.2 \times 10^{-30}^{***}$
log(Whls. Emp.)	0.16	0.44	0.661	1.62	7.16	$9.0 \times 10^{-12}^{**}$
log(Pop. Dens.)	0.06	0.24	0.811	-0.60	-4.85	$2.2 \times 10^{-6}^{**}$
log(Dist. to Auto.)	0.07	0.45	0.654	-0.19	-2.21	0.028**
L (0)		-756			-2539	
L ( $\hat{\beta}$ )		-528			-1614	
$p^2$		0.301			0.364	
$\bar{p}^2$		0.294			0.362	

Note: \*Significant at 90% confidence level; \*\*significant at 95% confidence level

We also tested the accessibilities to residential population and manufacturing industries, but the effects of those variables are quite limited or show even negative effects. It is surprising that, while *ShareEAZ*/*ShareLZ* and *Whls. Emp.* explain a large part of the spatial distribution of logistics facilities, the accessibilities to potential consumers play a limited role. The warehouse location choice model estimated for Toronto, Canada (Gingerich and Maoh, 2019) also indicates the strongest effect of industrial land use but such effect stands out even more in the Paris Region. A possible explanation for this is that the land supply for logistics activities in the Paris Region is very limited and the choices of locations are highly constrained to the historical clusters or the places reserved by zoning regulations. Furthermore, many logistics facilities in the Paris Region are part of supply chains that cover the entire nation (DRIEA, 2012; Guerrero and Proulhac, 2014), which might reduce the relative importance of the accessibility to local consumers among other factors.

Considering the fact that the EAZs and LZs play critical roles for the locations of logistics facilities in the Paris Region, we additionally estimated models that use only samples actually within EAZ and/or LZ. In this setting, population accessibility (defined below) is included in the utility function as it shows the significant positive effects, while it does not in the original models. Following Sakai et al. (2017), the accessibility to population<sup>2</sup> is defined as follows.

$$\text{Acce. Pop.}_l = \sum_m P_m \exp(-\log(D_{l,m})/2) \quad (4)$$

where:

$D_{l,m}$ : Network distance between location  $l$  and municipality  $m$

$P_m$ : Residential population of municipality  $m$

For the additional models, the size of EAZ and/or LZ is used as the scale of alternatives (i.e. potential locations are assumed to be limited to those in EAZs/LZs).

Table 5 and Table 6 show the estimated coefficients with and without *Acce. Pop.* as an IV. In case the alternative locations are limited to EAZ/LZ, *Acce. Pop.* clearly plays an important role to determine the locations for *LSP-CD*, *LSP-CD/S* and *DISTR-S*, which are supposed to serve, at least partially, for deliveries to retail shops and

<sup>2</sup> The summary statistics of the population accessibility (in millions) is as follows: mean: 1.78, median: 1.67, standard deviation: 0.43, minimum: 1.19, and maximum: 3.32.

end-consumers. *Whls. Emp.* became less significant compared with earlier models because EAZs/LZs in general have already high accessibility to wholesale employments. The effect is even less in the models with *Acce. Pop.*, except *LSP-S*. *Pop. Dens.* is again significant in the models for *LSP-S* and *DISTR-S* and, this time, also in the models for *LSP-CD*, both with and without *Acce. Pop.* Potentially, an operator would prefer an area where less passenger trips are generated for the facility that frequently generates goods vehicle trips; this significant effect is observable only in the situation where a location is chosen from EAZs/LZs. Lastly, *Dist. to Auto* has a significant effect only for *DISTR-S* like the models presented earlier.

Table 5: Estimated location choice models  
(LSP-CD, LSP-CD/S, and LSP-S; only EAZs and/or LZs are considered as alternatives)

Acce. Pop.	LSP-CD		LSP-CD/S		LSP-S	
	With	Without	With	Without	With	Without
ln(Acce. Pop.)	<b>Coef.</b> <b>0.73</b>		<b>0.81</b>		<b>-0.18</b>	
	t-val. 3.45		2.99		-1.07	
	p-val. $7.3 \times 10^{-4}**$		0.004**		0.286	
ln(Whls. Emp.)	<b>Coef.</b> <b>0.33</b>	<b>0.89</b>	<b>-0.11</b>	<b>0.47</b>	<b>0.67</b>	<b>0.53</b>
	t-val. 1.41	4.69	-0.39	1.89	3.02	3.05
	p-val. 0.160	$6.3 \times 10^{-6}**$	0.698	0.062*	0.003**	0.003**
ln(Pop. Dens.)	<b>Coef.</b> <b>-0.57</b>	<b>-0.36</b>	<b>-0.19</b>	<b>0.07</b>	<b>-0.34</b>	<b>-0.39</b>
	t-val. -4.13	-2.84	-0.97	0.35	-2.57	-3.11
	p-val. $6.1 \times 10^{-5}**$	0.005**	0.334	0.727	0.011**	0.002**
ln(Dist. to Auto)	<b>Coef.</b> <b>-0.08</b>	<b>-0.08</b>	<b>-0.03</b>	<b>-0.04</b>	<b>0.01</b>	<b>0.01</b>
	t-val. -0.76	-0.77	-0.24	-0.30	0.08	0.10
	p-val. 0.448	0.443	0.811	0.765	0.936	0.920
L(0)	-1143	-1143	-681	-681	-1128	-1128
L( $\hat{\beta}$ )	-954	-960	-564	-569	-954	-955
$\rho^2$	0.166	0.160	0.172	0.165	0.154	0.153
$\bar{\rho}^2$	0.162	0.158	0.166	0.160	0.150	0.150

Note: \*Significant at 90% confidence level; \*\*significant at 95% confidence level

Table 6: Estimated location choice models  
(MFR-S and DISTR-S; only EAZs and/or LZs are considered as alternatives)

Acce. Pop.	MFR-S		DISTR-S	
	With	Without	With	Without
ln(Acce. Pop.)	<b>Coef.</b> <b>0.18</b>		<b>0.62</b>	
	t-val. 0.66		3.06	
	p-val. 0.512		0.003**	
ln(Whls. Emp.)	<b>Coef.</b> <b>0.13</b>	<b>0.26</b>	<b>0.40</b>	<b>0.89</b>
	t-val. 0.42	0.99	1.78	4.89
	p-val. 0.676	0.326	0.077	$2.6 \times 10^{-6}**$
ln(Pop. Dens.)	<b>Coef.</b> <b>-0.24</b>	<b>-0.19</b>	<b>-0.67</b>	<b>-0.49</b>
	t-val. -1.12	-0.94	-5.08	-4.09
	p-val. 0.267	0.351	$1.1 \times 10^{-6}**$	$7.0 \times 10^{-5}**$
ln(Dist. to Auto)	<b>Coef.</b> <b>-0.12</b>	<b>-0.12</b>	<b>-0.24</b>	<b>-0.23</b>
	t-val. -0.72	-0.74	-2.28	-2.24
	p-val. 0.474	0.462	0.024**	0.027**
L(0)	-462	-462	-1190	-1190
L( $\hat{\beta}$ )	-391	-391	-973	-978
$\rho^2$	0.153	0.153	0.183	0.179
$\bar{\rho}^2$	0.145	0.146	0.179	0.176

Note: \*Significant at 90% confidence level; \*\*significant at 95% confidence level

It should be noted that the estimated models do not consider the intervention of local public authorities except zoning (EAZ and LZ); those authorities also have influence on facility locations through building permits to some extent. Thus, it should be considered that modeling results also reflect the preferences of local authorities as well as the owners of the facilities.

The significant factors for the locations of logistic facilities observed in our models, i.e. zoning, population density (which is also the proxy of land price), the accessibilities to wholesale businesses, and controlled-access highways, are consistent with the results of the past research such as Sakai et al. (2016), Kang (2018) and Gingerich and Maoh (2019). On the other hand, the degrees of the effects are different across different cities. For example, in the Tokyo Metropolitan Area (TMA), Japan, the average distance to local goods receivers is a key factor for location choices (Sakai et al., 2016); zoning regulations are influential, but they are not the decisive

factor. On the other hand, zoning regulations are critical in the Paris region and the accessibilities are only secondary factors. This suggests that, even though the outward migration of logistics facilities (i.e. logistics sprawl) is commonly observed across many cities, including the TMA and the Paris region, the mechanism that drives such spatial dynamics may differ by city.

## 7. Conclusions

The estimation of location choice models using detailed data developed for the Paris region by Heitz et al. (2017) unveiled the key locational characteristics that attract logistics facilities as well as the heterogeneity in the effects of the characteristics by activity category. The most important finding is that land use regulations and traditional clusters play a significant role for the locations of newly developed logistics facilities in the Paris region. It underlines the importance of zoning policies for logistics land use in this region. Zoning changes may cause significant impacts on the spatial distribution of logistics facilities, and thus, goods vehicle traffic. The dominating effect of zonings indicates that public authorities in the Paris Region have high potential to navigate the logistics facility locations for letting them cluster and avoid mixed development, which often deteriorate the residential environment; on the other hand, it also implies that the alternative locations for logistics facilities are not flexible and thus some facilities might not be able to choose optimal locations in terms of the proximity to their customers. The additional modeling exercise focusing on the choices from alternative locations in EAZs/LZs indicates that the locations close to end-consumers are preferred for the facilities which generate frequent delivery trips (i.e. *LSP-CD*, *LSP-CD/S* and *DISTR-S*), only if such locations are available within EAZs/LZs. Such preference could strengthen the effect of securing locations for logistics facilities near population clusters using zoning regulations to mitigate urban freight traffic impacts. On the other hand, the analyses of Sakai et al. (2017, 2018, 2019) for the TMA underline the complexity between the spatial distribution of logistics facilities and the externality associated with urban freight traffic. The present research does not directly quantify the influence of logistics facility locations on traffic impact. Future research on the relationship between the spatial distributions of logistics facilities and traffic impact in the Paris Region is expected to provide further beneficial policy insights and, thus, encouraged to be conducted.

This research has some limitations. As discussed earlier, some key variables, such as land price/rent and the accessibility indicator specific to each logistics facility, were not directly used in our location choice modeling. These variables should be used in the future studies. Furthermore, the model we used, MNL model, does not consider potential spatial autocorrelation due to unobserved factors. We tested a NL model (not presented in this paper), which considers the correlation in the unobserved components of the alternatives within the same municipality; however, it is more appropriate to use a model which allows for more flexible spatial autocorrelation structure such as Nguyen and Sano (2010) and Bhat and Guo (2004). We leave the logistics facility location choice analysis using such model specification, which typically requires high computational cost, as a future research task.

Notwithstanding these limitations, this research demonstrates the benefit of detailed spatial information of logistics facilities (and the methodology to collect and process such data) to obtain policy insights. The estimated models provide other insights; for example, locations with good autoroute-access would be ideal for encouraging the clustering of distributors. Except for logistics facility data, the data used in this research (i.e. demographic and transport information) are often available for public agencies. The future case studies of other cities using the methods for data collection and analysis proposed by Heitz et al. (2017) and this research is expected to reveal insightful homogeneity and heterogeneity of logistics facility location choices in different cities and their implications for land use policies.

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